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CHALLENGES OF THE IMPLEMENTATION OF MEMBRANE STRUCTURES INTO BIM

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Summary. This document presents the current situation of handling membrane structures within the BIM method, points out necessary steps to fully implement membrane structures into BIM and explains the benefit of an implementation.

1 INTRODUCTION TO BIM

In the age of industrialisation 4.0, dynamic processes of information and communication technology transform the work processes through computerisation. In the construction industry, this type of information-fusion is going to be implemented by the BIM method.

BIM is a communicative way of working, which makes it possible to work, plan and build together with all project participants from different disciplines and trades. The digital 3D model is at the centre of the planning process, as an anticipation of the spatial construction.

In addition to the already mentioned communicative cooperation method, the other important characteristic of the BIM idea is the phase-interrelated processing of the model, from the design to the approval phase to execution planning and construction. Even the operation phase and dismantling of the building could be taken into account. The method should enable a nearly loss-free information exchange between all involved parties [1].

This article is focusing on the implementation of Membrane Structures into BIM to reach the mentioned benefits of the BIM method when planning a Membrane Structure and continues and extend the concept papers presented by Lin et al. [2,3].

2 REPRESENTATION OF STRUCTURES IN BIM

Using the BIM method, all relevant information are linked to individual elements within the BIM model. The individual elements represent structural components of the overall structure as 3D solid bodies, surfaces or curves.

3D solid bodies and surfaces are flexible, based on the parametric concept of the BIM method. Solids and areas can be defined by using boundary representation, Non-Uniform Rational B-Spline, polygon mesh or other modelling technics. Besides the geometry the relation between the unique geometries are implemented as references within the BIM model to allow the parametric approach as well as a common reference system. This reference can be global and local coordinate systems, individual grid lines or reference planes.

In addition to these geometrical data also alphanumeric information can be attached to each BIM element like area data, specifications, naming of elements, product data, costs, time, technical standards - in short: component and project-specific data, like the value of the door width for example. This value directly communicates with the graphical wall opening. Geometric and alphanumeric data are linked to one another. Graphical changes to the door width will automatically change the appropriate value in the database.

Using the BIM method for both geometric and alphanumeric data, a format is available, which allows collaboration via a model-based, spatial and component-related data exchange. It also allows the joint storage of data together with their relationship. ISO 16739 describes this file-based and standardised interface, the Industry Foundation Classes (IFC). IFC is a data format for the manufacturer-neutral exchange of digital building models 4. IFC defines the syntax for all data of the model. Thanks to the open accessibility of this data structure and the associated neutrality, IFC has become the basis for almost all public building projects, which BIM obligates.

3 CURRENT SITUATION OF HANDLING MEMBRANE STRUCTURES IN BIM

Currently the setup of a BIM model is time-consuming, inefficient and follows these working steps: First, the geometry of the various structural elements must be generated and linked to the reference systems like coordinate systems, levels or other reference elements. This generation can be done element by element or using programming interfaces like Dynamo, Grasshopper or API-based text-based programming languages. Problems occur if geometries were generated by different software packages rather than the final BIM environment, which is mostly the case.

The IFC format currently does not include all relevant geometric description and proprietary formats like step, iges or dwg. It often shows problems referring the proper geometrical alignment and transfer into structural families of elements or the IFC-format is simply not available in the external packages. This issue must be solved by positioning and linking external element more or less manually within the final environment.

The next step is the integration of semantic information - a very time-consuming approach, especially because non-standard elements or tailored families have to be used. Non-systems internal plug-ins exist to automate the input of relevant data from external tables like Excel sheets. These plug-ins use programming interfaces like API's to include the semantic information into the BIM model.

To fully benefit from the BIM idea also information for project management coordination (time, other resources and so forth), data for the installation process as well as data for facility management purposes must be implemented and related within the BIM model of Membrane Structures.

4 IMPLEMENTATION OF MEMBRANE STRUCTURES AND CABLES IN THE BIM ENVIRONMENT

To simplify the planning process of Membrane Structures and to benefit from the advantages of the BIM method Membrane Structures need to be implemented in the BIM environment.

For the practical implementation, the description of classified component semantics is required. This description is the base on which the BIM method develops its strength and quality of interoperability during data exchange. The key to realizing this interoperability is the classification of components and its properties.

At the moment, there are various approaches around the world for the collection of structured product data. One such approach is, for example, the Construction Operations Information Exchange (COBie) format or the Product Data Templates (PDT), which provide the necessary information about products. In principle, it is important to categorize and classify the products to allow comparability of products from different manufacturers. In Germany, the DIN SPEC 91400 attempts to build an IFC-compliant component classification indirect connection to the performance specifications according to the *Standardleistungsbuch für das Bauwesen* (StLB), in which construction services for tendering, allocation and invoicing are described [5,6].

For many components a classification is already developed and products have been depicted so that these elements can be used as ready-made BIM objects in the planning process. However, this does not apply to the components required for membrane structures so far. First of all, a general data concept for Membrane Structures is needed, as proposed in the following chapter.

5 DATA CONCEPT

Membrane Structures can be reduced to a few standard elements:

- The membrane surface, segmented into individual membrane panels with welding seams
- The border connection elements such as corner plates, clamping profiles and coupling elements
- Embedded and boundary cables

Following the BIM structure, each element has to be described by geometric and alphanumeric data.

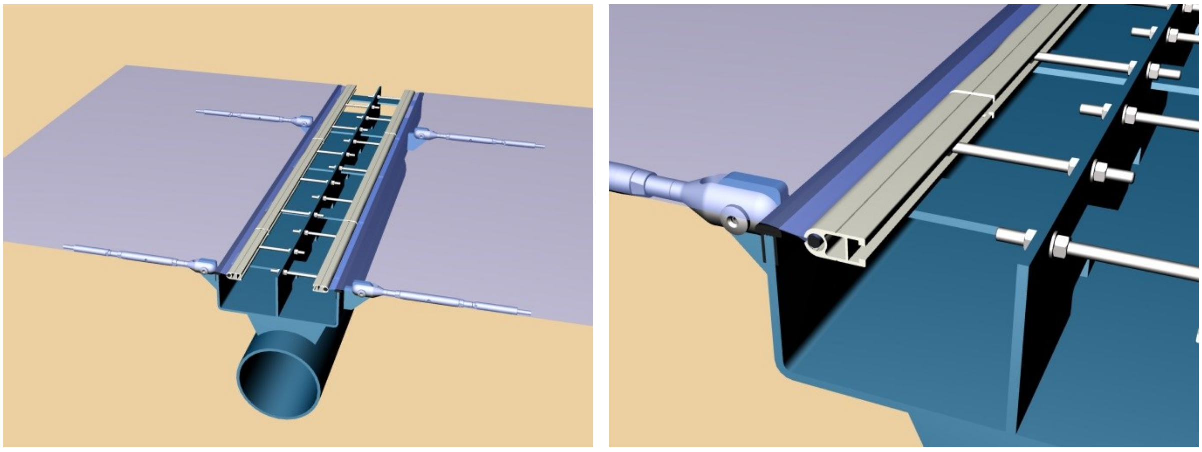

Fig.1a,b: Membrane Construction Detail showing all mentioned standard elements such as membrane surface, profile and cable support.

5.1 Geometric Data

Currently, geometric data of membrane surfaces represent a simplification of the structure. No highly detailed geometries, but a simplification of the shape as a function of the level of detail (LOD) is the standard illustration for most membrane structures in BIM[7]. Further consideration directs towards derivation of the workshop design and more precise analyses and will require higher detailed models (up to LOD 400/500). The idea behind is that not every BIM model of a membrane structure needs the same level of detail. The level of detail reaches from LOD 100, only system lines of used structural elements, up to the highly detailed description of every connection element following the "as build" geometry of a structure (LOD 500). A model used for coordination of different trades or visualization does not necessarily need the same depth as a model used for the manufacturing process and the derivation of workshop drawings (LOD400)

Membrane structures significantly change their geometries under different permanent and variable loads which lead to discrepancies between the perfect initial geometry and the gravity loaded and pre-tensioned structure. For most planning steps, the perfect geometry is required, but for others (i.e. installation planning) the deformed structure might be needed. Therefore different state-geometry descriptions within one model are needed.

In addition, the structure will require a flexible parametric representation of the membrane surface including local coordinate and reference systems. The reference systems would allow the linking of the all connected elements like welds, boundary cables or edge connection. State of the art is to represent membrane fields as individually inflexible polygon meshes only.

The need of a flexible parametric representation also applies for border connection elements. How this dynamic adaption to geometry changes could be implemented is shown in the Grasshopper code provided by the University Budapest [8]. These real-time algorithms are visualizing detail structures in Rhino such as corner plates, allowing constant alteration of the base geometry until the user wishes to freeze the model.

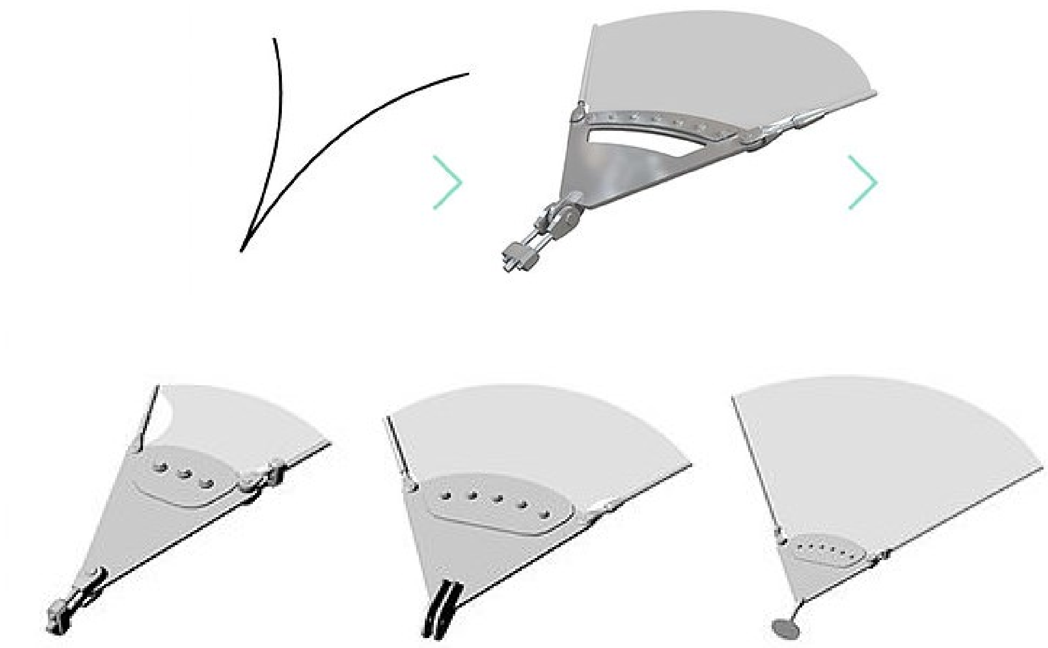

Figure 2 a-e: “Basic Corner Script” published at www.membranedetail.com [8]

The currently used representation of cables as polylines is imprecise and should be improved by using 3d splines. In general, cables follow freeform-curves as a result of forces, perpendicular to the center line of the cables. To allow connection of cable clamps and other cable attachments, a local coordinate system following the direction of the spline should be defined and implemented (Fig. 3).

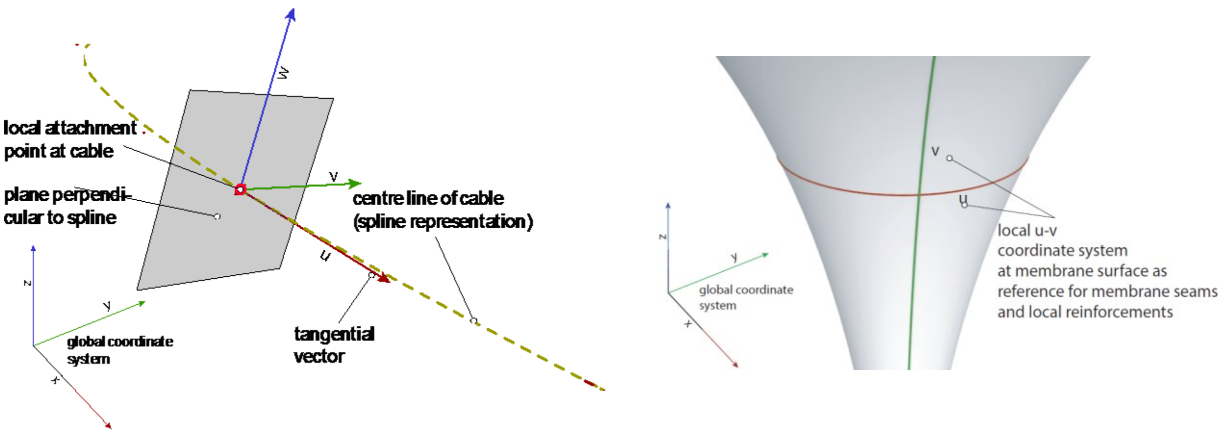

Figure 3a, b: Local reference system for cable attachments and membrane surface

5.2 Alphanumeric Data

In addition to geometric data relevant information can also be stored as alphanumeric data. The alphanumeric data can be divided into structured and unstructured data. Unstructured data is mostly manufacturer information, which is provided in any format (data sheets, assembly instructions, approval document). Since the format and thus the content is not determined, there is no precise definition of the unstructured data.

The following list contains aspects of information relevant for membrane surfaces:

Product data:	Type, Mesh/Solid, Base fabric material, Coating, Total Weight, Thickness, Width, Tensile strength (warp/weft), Tear resistance (warp/weft), Adhesion, Translucency, Flame retardancy, VLT, SHGC, Youngs modulus (warp/weft)
Geometric data:	Area, Curvature (Description as a NURBS-surface or poly mesh, nodes should be define further detail alignment (edge details, corner details, drainage elements) seams should be depicted as splines or polylines
Design data:	No of Edges, Edge detail, No. of Corners, Corner detail, No of Highpoints, Highpoint Detail, No of Suction Lines, Suction Detail, No of Cable support, Cable pocket detail, No. of seam lines, seam line width, keder material, keder diameter
Production data:	Producer, Production Date, Batch No., Time, Status
Fabrication data:	Fabricator, Production Date, Cutting Pattern assignment, Details, Time, Status
Installation data:	Date, Installer, Time, Status
Testing data:	Certificates, Status
Further Data:	Price, Order Date, Order No.,

The following list contains structured information relevant for Cables:

Product data:	Type, Base material, Coating, Total Weight, Diameter, Length, Youngs modulus, metallic cross-section, unstretched length, minimum breaking load, ultimate load, material safety factor, end terminals
Geometric data:	Length, Pre-Tension, Curvature, points (nodes) for further details (cable clamps), markings
Design data:	No of Terminals, Terminal detail, No. of Clamps, Clamps detail
Production data:	Producer, Production Date, Batch No., Time, Status, raw material
Fabrication data:	Fabricator, Production Date, Details, Time, Status
Installation data:	Date, Installer, Time, Status, Pre-Tension
Testing data:	Certificates, Status
Further Data:	Price, Order Date, Order No.,

Various geometric and semantic values must be stored and handled within one model to allow an efficient planning process of Membrane Structures in the BIM method.

5.3 Further implementation steps

If the BIM model is used for analyses, like thermal-, shading or structural verifications additional properties must be added to elements of the BIM model (i.e. properties describing the long-term behavior of the structure must be integrated to compensate time-related effects).

Membrane and cable specific form-finding processes and creation of cutting patterns are further membrane-specific planning processes for which special information is needed. The geometry of the membrane surface is usually complex and is determined using form-finding processes. The shape depends on the material properties of the membrane, the applied pre-tension, its fixation to the substructure as well as the boundary conditions of the membrane surface. It can be assumed that the surface is created with special shape-finding software and then read into the 3D BIM model. Here, a corresponding linkage of the surface parts with the relevant information of the material is required. It is desirable that the current software tools for the creation of membrane surfaces conform to the data standard and thus output the calculated geometries as a BIM object. The required developments can be categorized in four topics:

Geometry and form-finding generation

- Development of flexible membrane and cable families linked to the form-finding process
- Alternative form-finding processes within the BIM environment or bi-directional links to form-finding software
- Simplification of integration of external geometric properties and transformation into structural families
- Developments for more than global geometry within one model

Input of semantic information

- Development of tailored feeding algorithms
- Development of bidirectional links between project management software packages

Processing of semantic information

- Better integration of assembly sequences within the standard BIM environment by integration of enhanced grouping and filtering functions
- Standardization of bi-directional connections to external software packages like MS-project or others

Legal issues

Like for most other structures, different companies are involved, legal issues have to be taken into account. Currently main unsolved questions are:

- How to protect the intellectual property at high levels of detailing such as LOD 300 at specific developed construction elements and details?
- How to define the responsibilities for the geometric position of individual elements used by several planners?

Last but not least concepts of using the BIM model as a base for schedule and cost control as well as the installation process, also known as 4D (time) and 5D (costs), are possible. This approach requires the preceding input of necessary connection of corresponding information into the BIM model.

6 CONCLUSION

To directly derivate all information from one BIM model is currently unrealistic because of the typical decentralized planning process with many specialized planners and manufacturers using individual applications. The use of different software environments results in individual drawing formats which currently must be assembled in the final BIM model more or less manually.

The standardized IFC format could bridge these applications and would allow to bring all information into one model if once the data structure for Membrane Structures are defined. It would avoid working with different non-related models which is insufficient, ineffective, error-prone, but currently still state of the art.

The implementation of BIM into the field of membrane and cable structures has just begun. Currently, not all expected benefits of the BIM method are reached. Reasons for that lack are defined within this article. The necessity for different levels of details (LOD) related to the process requirements as well as the enrichment of the IFC-Format concerning membrane structures was discussed. Current problems using BIM for Membrane Structures were mentioned as well as necessary further developments for an easier generation, information input and information processing were given. A further progress should base on research in the described directions and implementation and evaluation within the industry.

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